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THE IMPACT OF VARIABLE PRICING ON THE TEMPORAL DISTRIBUTION OF TRAVEL DEMAND

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ABSTRACT

Despite the potential of congestion pricing to ease the nation's ever-increasing congestion problems, there is little quantitative evidence of its ability to spread peak travel demand more efficiently over the course of the day. The objective of this paper is to assess the impact of variable pricing on the temporal distribution of demand, in order to investigate further the role of variable pricing as a travel demand management tool. The Variable Pricing Program of Lee County, Florida, was utilized as the data source for this study. Due to the limited congestion experienced at the program location, the effects of travel cost changes on the temporal distribution of demand could be isolated. It was found that program implementation had minimal impact on the overall distribution of demand. Demand for peak-period travel remained relatively unaltered, and active peak spreading was not observed. At the more micro-level however, program impact was more apparent, with significant temporal shifts in the proportion of demand within individual half hour time segments. Further analysis revealed a price elasticity relationship that was consistent with existing literature. A relationship was also observed between the extent of pre-program peak spreading and the subsequent percentage reduction in peak-period travel demand following program implementation. This finding suggests the potential to predict the active peak spreading that may result from congestion pricing. The fact that substantial temporal shifts in travel demand were observed in response to a discount of only $0.25 highlights the potential of variable pricing as a travel demand management tool.

Keywords: variable pricing, congestion pricing, elasticity, peak spreading, travel demand, TDM

INTRODUCTION

Congestion pricing is a potentially powerful travel demand management (TDM) strategy capable of significantly influencing travel demand characteristics on the nation's highways. Recent technological advances in electronic toll collection have allowed congestion pricing to become a realistic means of controlling congestion without incurring the large capital investments, environmental impacts, and social costs that characterize the traditional solution of further highway capacity expansion. Despite this potential, the viability of congestion pricing is currently not well known due to the limited knowledge of the multitude of potential impacts that it could impose. Central to determining the range and extent of these impacts is the need to understand how time-of-day based pricing, also known as variable pricing, impacts the temporal distribution of demand[1].

The objective of this paper is to investigate the impact of variable pricing on the temporal distribution of travel demand, in order to gain further insight into the ability of variable pricing to manage travel demand. Data used for this analysis were obtained from the Lee County Variable Pricing Project in the Fort Myers region of southwest Florida. This area experiences minimal congestion (the variable priced toll bridges operate at level of service C) and, therefore, changes in the temporal distribution of traffic may primarily be attributed to the monetary incentive associated with traveling in the off-peak periods. Thus, this case study allows one to isolate the impacts of variable pricing on demand.

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[1] In this paper, the terms congestion pricing and variable pricing are used interchangeably. Both terms represent time-of-day based pricing, although some of the literature uses the term variable pricing when time-of-day pricing is introduced in the absence of congestion.

BACKGROUND

The basic purpose of congestion pricing is to spread travel demand more efficiently over the course of the day by charging a user fee that varies according to changing levels of demand. At present, little is known on the extent to which congestion pricing programs are able to shift peak-period demand. This is due mainly to the lack of real-world congestion pricing projects. Another complicating factor is that the extent to which demand is shifted depends on the influence of the pricing strategy on the generalized travel cost of the facility, which is typically measured as a combination of travel time and travel cost. It is the complex interaction of these two variables, and the fact that congestion pricing affects both simultaneously, that has made it difficult for researchers to isolate the effect that each one has on travel demand.

Quantitative analysis of changes in the temporal distributions of demand have so far been limited to passive peak spreading, where the period of peak demand increases in size due to increasing levels of congestion. A study by Louden et al *(1)* studied the passive peak spreading phenomenon using traffic data from corridors in Arizona, Texas, and California. The ratio of peak-hour volume to peak-three-hour-period volume was used to represent the extent of passive peak spreading, and a model was developed that established a functional relationship between peak-hour to peak-period ratio and the level of existing congestion. Another study focused on temporal changes in travel demand within the Greater Toronto Area *(2)*. Using the model developed by Louden et al *(1)*, a significant correlation between congestion and peak spreading was again observed. In this paper, the technique used in the context of passive peak spreading is applied to the study of active peak spreading resulting from variable pricing, using data from the Lee County Variable Pricing Program in southwest Florida.

THE VARIABLE PRICING PROGRAM

Lee County's Variable Pricing Program was implemented on August 3rd, 1998, and involved altering the toll structure at two bridges called the Cape Coral and Midpoint bridges. The objective of the program was to encourage peak-period bridge users to switch their travel time to off-peak periods in order to spread demand more evenly over the day. Due to a strong negative response from the public to toll increases during peak-periods, it was decided to encourage off-peak travel by lowering the toll in the periods to either side of the peaks, commonly known as shoulder periods *(3).* The County Commission also explicitly stated that there would be no toll increases in the foreseeable future. The new toll structure offers a 50 percent discount on the regular toll to bridge users driving a two-axle vehicle fitted with a transponder and prepaid account. These users take advantage of the electronic toll collection systems at the bridges and are referred to as "eligible" users. The discount is available from 6:30 a.m. to 7:00 a.m., 9:00 a.m. to 11:00 a.m., 2:00 p.m. to 4:00 p.m., and 6:30 p.m. to 7:00 p.m. and is available only on regular weekdays, with no discount offered on weekends or public holidays.

Approximately 25 percent of bridge users are eligible for the variable pricing discount. The eligible user group is divided into two subcategories, those paying $1.00 during regular periods and $0.50 during discount periods, and those paying an annual fee of $40.00 in order to pay $0.50 during regular periods and $0.25 during discount periods. The vast majority of eligible users, approximately 93 percent, fall into the category paying $0.25 within discount periods.

There are several unique aspects of the Variable Pricing Program. First, the scheme does not attempt to spread peak demand through increased peak-period tolls. Instead, incentive for off-peak travel is provided by reducing the toll on either side of the peak-period. Second, the bridge locations of the program mean that the potential for route switching due to program implementation is minimized; thus, it is unlikely that demand is induced from or displaced to alternate routes. Third, only a small proportion of the total traffic is eligible for the discount. Therefore any observed changes within the eligible user group can be compared against any observed changes among ineligible users (who thus serve as an effective control group). Fourth, this pricing program is unique in that it is implemented at locations of limited congestion. Traffic conditions at the Cape Coral Bridge were improved from level of service E to level of service C by the opening of the Midpoint Bridge in October 1997. Traffic conditions have remained at level of service C since that time. The limited presence of congestion means that program implementation can have little impact on performance characteristics at the facilities. Therefore, the impact of price change on travel demand can be studied without the potential bias resulting from alterations in congestion levels, which, in turn, affect trip-timing behavior. One drawback of the program is that the recent opening of the Midpoint Bridge altered travel patterns to such an extent that it is difficult to use data collected prior to the opening of this bridge for comparison purposes.

DATA

The data used for this analysis comprised traffic count data obtained from the toll plazas at the Midpoint and Cape Coral bridges. Each vehicle transaction is recorded by the plaza computer, with the time of transaction, number of axles, and payment method used to ascertain eligibility for the variable pricing discount. These data were then compiled into a format that provides, for each half hour period throughout the day, the number of bridge users within each payment type category. Further cleaning of the data was carried out to remove all weekends and public holidays from the data set as the variable pricing discount is not available on these days. The traffic counts were then aggregated across the various payment type categories into two categories of eligibility status - eligible for variable pricing discount and ineligible for variable pricing discount.

METHODOLOGY

The basic approach used to assess temporal demand shift due to variable pricing was to define and compare two assessment periods, the first period being before and the second period being after variable pricing implementation. The relatively recent opening of the Midpoint Bridge, in October 1997, altered travel patterns in the region to a degree that it is difficult to utilize any pre-1998 traffic data. Therefore, the assessment periods defined for analysis in this study were January to June 1998, the six-month period prior to program implementation, and January to June 1999, the same six-month period after program implementation the following year. Utilizing the same six months of traffic data from subsequent years minimized the potential for bias due to seasonal variation, while maximizing the amount of available data. Also, the utilization of data from January to June 1999 to represent traffic conditions under variable pricing removed the potential for bias due to initial, short-term impacts being included in the analysis, allowing longer-term changes in demand distribution to be revealed.

Following the removal of non-variable pricing days from the data set, there remained 127 days of complete 24-hour data within each of the two assessment periods, resulting in a total of over 6,000 hours of comparison analysis data. From these data, the average traffic volume within each half-hour time segment was obtained. Thus, a robust single distribution of average half-hourly traffic was used to represent the temporal distribution of total travel demand. To assess changes in the temporal distribution of travel demand, the demand within each half hour was expressed as a percentage of total daily demand; thus removing the influence of changes in magnitudes of traffic volumes between assessment periods. The behavior of the ineligible user group was used as a control against which the behavior of the eligible users could be compared. This allows the isolation of the impacts of variable pricing on eligible users.

AGGREGATE IMPACT OF VARIABLE PRICING ON THE TEMPORAL DISTRIBUTION OF DEMAND

Figures 1 to 4 provide the distributions of daily travel demand within each half hour before and after variable pricing implementation at the Midpoint and Cape Coral bridges, for the eligible and ineligible user groups respectively. Considering the eligible users at the Midpoint Bridge, shown in Figure 1, it is apparent that variable pricing has had a minimal impact on the overall temporal distribution of demand. Slight deviations from the pre-variable pricing demand distribution are observed during the discount periods, which resulted in slightly reduced levels of peak-hour demand. At the Cape Coral Bridge, similar deviations during discount periods are evident, although this appears to have less impact on the magnitude of peak-hour demand. Despite minor reductions in peak-period demand, there is little evidence of any active peak spreading effects at either bridge, and the basic pattern of the daily demand profiles remain unchanged. It is also apparent that the demand profile of the Midpoint Bridge is more heavily peaked than that of the Cape Coral Bridge, suggesting that a larger proportion of commuters use this bridge.

In contrast, the distributions of ineligible user demand, shown in Figures 3 and 4, are almost identical before and after variable pricing implementation. This observation provides further evidence that the slight changes in temporal demand distribution within the eligible user group result from variable pricing. A Chi-Square test was carried out on the data to assess the significance of the changes in the temporal distributions of travel demand within the eligible and ineligible user groups. An assessment of the impact on total traffic, combining eligible and ineligible users, was also undertaken. The results of these tests are provided in Table 1 below.

Table 1: Chi-Square Test of Significant Change in Observed Distributions

Temporal Demand Distribution before Variable Pricing	*Temporal Demand Distribution after Variable Pricing*	*Calculated Chi-Square Values*	
		Midpoint	*Cape Coral*
Eligible Users	Eligible Users	13.21	8.12
Ineligible Users	Ineligible Users	1.57	4.81
Total Users	Total Users	5.41	5.82

$\chi^2_{\text{critical } (\alpha=0.05)} = 38.9$

Comparing the critical chi-square value of 38.9 with those test statistic values obtained for the within group comparisons, it is observed that all three groups considered in the table are not significantly impacted by variable pricing implementation. However, it can be seen that, at both bridges, the chi-square test values comparing distributions of eligible users are the largest in magnitude. This provides a potential indication that the differences between the temporal distributions of eligible users are greater than those for the other groups in the table. Overall, these results indicate that, at the macro level, there is a minimal overall impact of variable pricing on the travel demand distribution of eligible users. Therefore, it was considered prudent to examine changes in travel demand at the more macro-level as well.

DISAGGREGATE IMPACT OF VARIABLE PRICING

The analysis in this section focuses on these localized temporal demand shifts in more detail by assessing the percentage change in the proportion of demand within each half hour time segment between 6:00 a.m. and 7:30 p.m. Figures 5 and 6 present the results of this analysis at the Midpoint and Cape Coral bridges.

Considering eligible users at the Midpoint Bridge, shown in Figure 5, the impact of variable pricing is clearly evident. Positive shifts in demand are observed within all discount periods, while negative shifts in demand occur during peak-periods. It can be observed that the impact during the morning peak is greater than that observed during the afternoon peak. There is a positive demand shift of 17.8 percent during the pre-morning-peak-period, in contrast to the mere 2.7 percent shift during the post-afternoon peak discount period. A potential reason for the larger impact during the morning peak is that this period is more heavily peaked than the afternoon peak. Therefore, a greater proportion of morning peak users are able to consider altering their travel time to obtain the discount. Another reason for the larger morning peak impact is that the post-afternoon peak discount period runs from 6:30 p.m. to 7:00 p.m., which, at present, is rather late in the day to influence the majority of return trip commuters. It is expected that, as overall travel demand increases over time, the passive peak spreading effect will allow this period to attract a greater proportion of return trip commuters. In contrast, the 6:30 a.m. to 7:00 a.m. discount period is more appropriately placed to attract morning commuters.

It can also be observed that the greatest impact occurs at the boundaries between the regular-priced and discount-priced periods, with smaller demand shifts generally observed during times further away from these boundaries. This effect was expected as the likelihood of users to alter their travel time is directly related to the magnitude of the travel time change they have to make. This also explains why the greatest impact is generally observed during the discount periods of half-hour duration, as these periods attract users from both sides of the half-hour.

Considering the shifts in demand at the Cape Coral Bridge, shown in Figure 6, the same clear pattern of variable pricing impact, greater in the morning peak, is observed. However, the overall magnitude of the impact at this bridge is smaller than that observed at the Midpoint Bridge. During the morning peak, small, insignificant positive demand shifts are observed during the peak-hour, while demand on either side of the peak hour, at the boundaries of the peak-period, is significantly reduced. A one-way analysis of variance (ANOVA) test was performed on the data to assess the significance of the temporal demand shifts. Table 2 shows the results of this test.

Table 2: ANOVA Test of Demand Shift Significance
Summary Table of F-Statistics

Time	*Midpoint Bridge*	*Cape Coral Bridge*
6:00-6:30	125.81(-)	15.77(-)
6:30-7:00	176.93(+)	65.28(+)
7:00-7:30	125.03(-)	112.79(-)
7:30-8:00	22.26(-)	0.16
8:00-8:30	7.22(-)	0.19
8:30-9:00	36.26(-)	29.91(-)
9:00-9:30	17.30(+)	57.99(+)
9:30-10:00	4.04(+)	14.19(+)
10:00-10:30	15.15(+)	5.11(+)
10:30-11:00	24.11(+)	15.32(+)
11:00-11:30	0.00	5.39(-)
11:30-12:00	0.83	0.57
12:00-12:30	2.98	0.00
12:30-13:00	0.02	3.73
13:00-13:30	1.19	11.20(-)
13:30-14:00	1.72	2.48
14:00-14:30	5.42(+)	29.47(+)
14:30-15:00	19.26(+)	23.71(+)
15:00-15:30	20.53(+)	25.11(+)
15:30-16:00	16.68(+)	23.26(+)
16:00-16:30	0.09	0.03
16:30-17:00	23.97(-)	9.73(-)
17:00-17:30	16.27(-)	11.17(-)
17:30-18:00	13.15(-)	0.99
18:00-18:30	8.37(-)	5.25(-)
18:30-19:00	4.02(+)	0.89
19:00-19:30	3.21	0.18

α:	0.05
F-Critical:	3.89
(+) and dark shading:	Period of significant positive demand shift
(-) and light shading:	Period of significant negative demand shift

At $\alpha = 0.05$, temporal shifts in demand greater than approximately 2.6 percent were found to be significant. Therefore, the majority of demand shifts during the peak and discount periods were found to be significant. As expected, eligible peak-period traffic volumes decreased significantly while discount-period traffic volumes increased significantly. This test again shows that the impact is observed to be greater at the Midpoint Bridge. It is suggested that this is again related to the extent of peaking at the respective bridges. The geographic location of the Cape Coral Bridge results in a greater proportion of beach users and other recreational travelers within the eligible user group at this bridge. The greater proportion of commuters at the Midpoint Bridge, traveling daily during peak-periods, facilitates the greater impact of variable pricing. This hypothesis is subject to further testing using a survey of bridge users undertaken in May 1999.

PRICE ELASTICITIES

In this section, the relationship between travel cost and travel demand, as evidenced by the Variable Pricing Program, is investigated. Table 3 compares the proportion of eligible user daily travel demand within the peak and discount periods before and after variable pricing implementation. The subsequent percentage shift in travel demand within each of these periods is also provided.

Table 3: Shifts in Eligible User Demand from Regular Priced to Discount Priced Periods

Time Period	*Midpoint Bridge*			*Cape Coral Bridge*		
	% of Daily Demand		*% Demand Shift*	*% of Daily Demand*		*% Demand Shift*
	Pre VP	*VP*		*Pre VP*	*VP*	
Pre-AM Peak Discount (6:30 a.m.-7:00 a.m.)	4.1	4.8	17.8	3.1	3.4	10.0
AM-Peak (7:00 a.m. – 9:00 a.m.)	19.5	18.0	-7.5	16.9	16.3	-3.8
Post AM Peak Discount (9:00 a.m. – 11:00 a.m.)	8.6	9.1	5.6	10.1	10.6	5.4
Off-Peak (11:00 a.m. – 2:00 p.m.)	13.3	13.4	0.6	15.6	15.3	-1.9
Pre-PM Peak Discount (2:00 p.m. – 4:00 p.m.)	11.9	12.5	5.6	12.5	13.2	5.4
PM-Peak (4:00 p.m. – 6:30 p.m.)	23.1	22.2	-4.0	21.4	20.9	-2.3
Post- PM Peak Discount (6:30 p.m. – 7:00 p.m.)	2.9	3.0	2.7	2.9	2.9	1.3

This table clearly shows the shifts in demand from regular priced to discount priced periods. The table also shows the extent to which program impact varies between the different peak-periods and between each bridge. The reduction in demand within each peak-period at the Midpoint Bridge is observed to be almost twice that observed at the Cape Coral Bridge. Also, the morning peak impact is observed to be greater than the afternoon peak impact, as discussed previously.

This temporal demand shift data was used to consider the relationship between travel cost and travel demand. This relationship is often addressed through the concept of price elasticity of demand. Price elasticity of demand is defined as the percentage change in demand per unit percentage change in cost. The literature suggests that such elasticites tend to range from –0.1 to –0.2 at the low end to –0.3 to –0.4 at the high end, depending on pricing level, current travel costs, and extent of existing transportation capacity *(4), (5).* This means that a 10 percent reduction in price results in a 1 to 4 percent increase in demand. The percentage changes in demand, shown previously in Table 3, were used to compute elasticities for each discount period at each bridge. The results are provided in Table 4.

Table 4: Price Elasticities

Discount Period	*Midpoint Bridge*			*Cape Coral Bridge*		
	% change in price	*% change in demand*	*calculated elasticity*	*% change in price*	*% change in demand*	*calculated elasticity*
Pre-Morning-Peak	-50.0	17.8	-0.36	-50.0	10.0	-0.20
Post-Morning-Peak	-50.0	5.6	-0.11	-50.0	5.4	-0.11
Pre-Afternoon-Peak	-50.0	5.6	-0.11	-50.0	5.4	-0.11
Post-Afternoon-Peak	-50.0	2.7	-0.05	-50.0	1.3	-0.03

The table shows the range of elasticites that exist for each discount period. The large demand shift during the pre-morning-peak-period at the Midpoint Bridge results in an elasticity of –0.36, which is toward the upper bound of the range specified in the literature. During the periods where the discount extends over two hours, the post-morning-peak-period and the pre-afternoon-peak-period, the elasticities are very similar, with each period at each bridge producing an elasticity of -0.11. The small temporal shift in post-afternoon-peak demand at each bridge results in relatively small elasticity values (–0.03 and –0.05) for this period. Besides the high elasticity value of –0.36 observed during the pre-morning peak discount period at the Midpoint Bridge, the calculated elasticities are generally in the low end of the range specified in the literature, with all values equal to –0.20 or less. These relatively small elasticities represent the demand response to travel cost change only, since there is little travel time improvement gained from traveling in the discount periods. This lack of congestion and, therefore, travel time incentive may have caused the elasticities to fall within the low end of the expected range.

PEAK SPREADING AND VARIABLE PRICING IMPACT

It is apparent from existing literature that there is need for a greater understanding of how variable pricing affects the temporal distribution of demand. Quantitative analyses of peak spreading effects have been limited in the literature to passive peak spreading assessment, while little research is available on the quantification of the active peak spreading effect afforded by toll structures that vary in response to changing levels of demand. It would be useful, therefore, to find a means of quantifying the relationship between variable pricing and its effect on peak spreading. In this paper, this relationship is considered using the Peak Hour to Peak Period Ratio (PHPPR), which is defined as the ratio of the peak-hour traffic volume to the peak-three-hour-period traffic volume. This is used as a measure of peak spreading. This ratio was calculated for the morning and afternoon peak at each bridge, both before and after variable pricing implementation. The ratios were then tabulated against the calculated percent reductions in peak-period[2] demand shown in Table 3. The results of this tabulation are shown in Table 5.

Table 5: Comparison of Peak Hour to Peak (Three Hour) Period Ratio with Percentage Reduction in Peak-Period Demand

Characteristic	*Midpoint Bridge*		*Cape Coral Bridge*	
	Morning Peak	*Afternoon Peak*	*Morning Peak*	*Afternoon Peak*
PHPPR before Variable Pricing	44.7	41.2	41.3	39.4
PHPPR after Variable Pricing	41.6	40.3	41.7	38.9
% Reduction in Peak-Period Demand (see Table 3)	7.5	4.0	3.8	2.3

From Table 5 it can be observed that, in three of the four cases, variable pricing implementation has succeeded in reducing the PHPPR value, indicating a spreading of demand. The exception to this observation is the morning peak at the Cape Coral Bridge, where the PHPPR value nominally increased from 41.3 percent to 41.7 percent, despite the fact that there was an overall

[2] The peak-periods defined in the Variable Pricing Program, 7:00 a.m. to 9:00 a.m. and 4:00 p.m. to 6:30 p.m., differ from the peak three hour periods used to calculate the PHPPR values, which occur from 6:30 a.m. to 9:30 a.m. and 3:30 p.m. to 6:30 p.m. The peak three-hour period was used in the PHPPR calculations to retain concurrency with previous peak spreading analyses. In this paper, the term “peak-period” refers to the periods defined in the Variable Pricing Program.

reduction in peak-period demand. This observation can be explained through an examination of Figure 2, which shows that morning peak-hour demand actually increased slightly despite variable pricing implementation. The overall peak-period demand reduction resulted from significant demand reductions on either side of the peak hour.

Table 5 also shows that a correlation appears to exist between the PHPPR value before program implementation and the subsequent reduction in peak-period demand. The largest peak-period demand reduction occurred at the Midpoint Bridge during the morning peak-period (7.5 percent demand reduction), which is also the most heavily peaked of the four periods assessed (highest PHPPR value before variable pricing). The smallest impact was observed at the Cape Coral Bridge during the afternoon peak-period (2.3 percent demand reduction), which also happens to have the smallest PHPPR value.

To further understand this relationship, the PHPPR and percent reduction in peak demand were plotted against each other, as shown in Figure 7. An inspection of this figure suggests a linear relationship between these two variables despite the fact that two different locations are being considered. A least squares regression line was estimated to quantify the relationship, and its equation is provided within the figure. The equation shows that, a 1 percent increase in the value of PHPPR, there is a 0.996 percent decrease in peak-period demand as a result of variable pricing. This suggests that an elasticity approximately equal to unity exists between these two variables, although one must recognize that this value is clearly sensitive to the level of toll discount offered.

It is premature to draw any definite conclusions from this analysis as only four data points, over a relatively small range of traffic conditions, are available to quantify the relationship. However, the results of this analysis are important in that it suggests a quantifiable relationship between peak spreading and time-of-day pricing thus providing the potential to predict the active peak spreading effect of a congestion pricing scheme. The computed elasticity between PHPPR and peak-period demand reduction could also be used as a predictive tool in active peak spreading modeling efforts. Further work is required to validate the existence of this relationship and it would be useful to assess this relationship at other locations with different congestion levels.

CONCLUSION

This paper has assessed the impact of variable pricing on the temporal distribution of travel demand at both the aggregate and disaggregate levels, and quantified the relationship between travel demand and travel cost through the computation of price elasticities of demand. Considering the aggregate impact, it was found that scheme implementation failed to introduce an active peak spreading effect. Peak-hour demand was slightly reduced but the basic size and temporal orientation of the peak-periods remained as before. Chi-Square test results provided further evidence of insignificant macro-level impact. However, the aggregate analysis did show that localized positive temporal shifts in demand had occurred during discount periods that resulted in slight reductions in peak-period demand. The behavior of the ineligible user group (control), who could not take advantage of variable pricing, was as expected, with negligible shifts in demand observed between assessment periods. This finding lends credence to the conclusion that the shifts observed within the eligible user group were as a result of the Variable Pricing Program. The impact of variable pricing on total traffic was, again, found to be negligible, which is as expected considering the large proportion of ineligible users within the total traffic stream.

The disaggregate level analysis further investigated these effects, and it was found that significant positive shifts in demand occurred during discount periods while significant negative shifts in demand were observed during peak-periods. It was observed that the morning peak-periods were impacted more greatly at each bridge and that the Midpoint Bridge generally experienced a greater impact than the Cape Coral Bridge. The authors suggest that the greater impact at the Midpoint Bridge results from a larger proportion of commuter traffic at this location, with the greater proportion of peak-period travelers allowing greater potential for variable pricing impact. It is suggested that the greater morning peak impact also results from demand during this period being more heavily peaked. The afternoon peak impact is further reduced by the post-afternoon peak-period not starting until 6:30 p.m., which may currently be too late to attract return trip commuters.

Price elasticities of demand were computed for each discount period at each bridge, and a range of elasticities between –0.03 and –0.36 was found. Discounting the large elasticity of –0.36 observed during the pre-morning peak at the Midpoint Bridge, the calculated elasticities were toward the low end of the range specified in the literature *(4),(5)*. A relationship was found to exist between the extent of pre-variable pricing peak spreading and the subsequent reduction in peak-period travel demand. It was found that for every 1 percent increase in the Peak Hour to Peak Period Ratio, used to represent peak spreading, there is a 1 percent reduction in peak-period travel demand. Although this relationship was produced using limited data, it suggests the potential to predict the active peak spreading effect afforded by time-of-day pricing. Future research should attempt to study further this relationship under a wide range of contexts.

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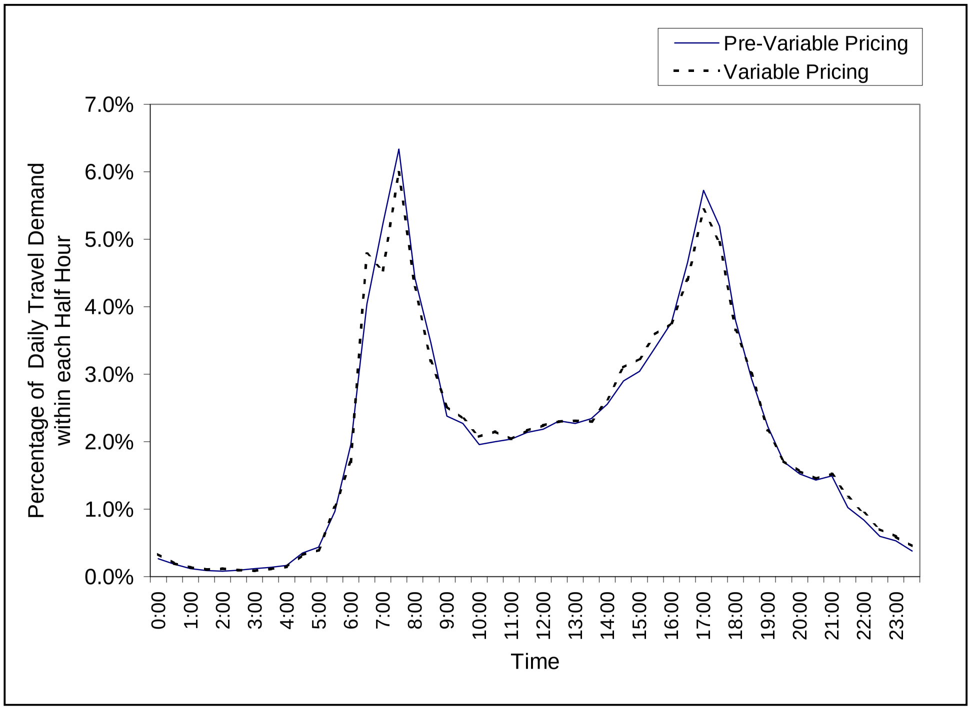

Figure 1: Temporal Distribution of Eligible User Demand at the Midpoint Bridge

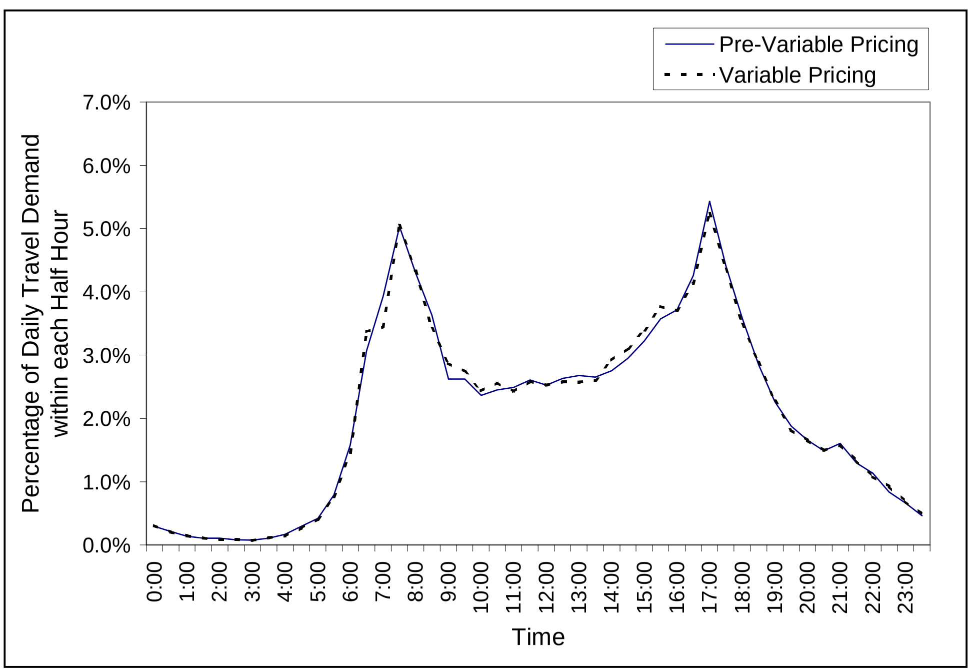

Figure 2: Temporal Distribution of Eligible User Demand at the Cape Coral Bridge

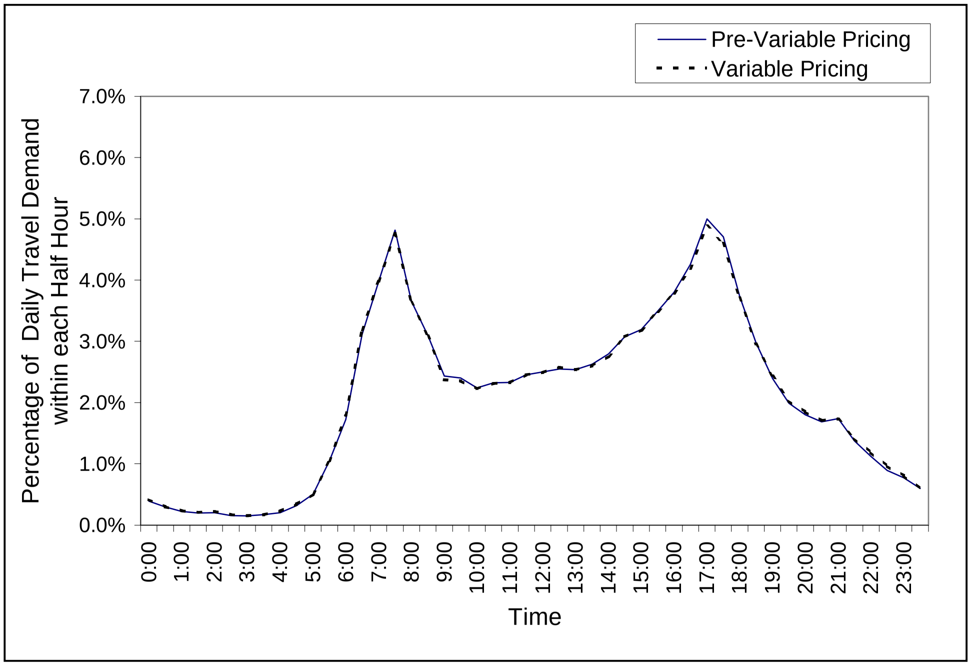

Figure 3: Temporal Distribution of Ineligible User Demand at the Midpoint Bridge

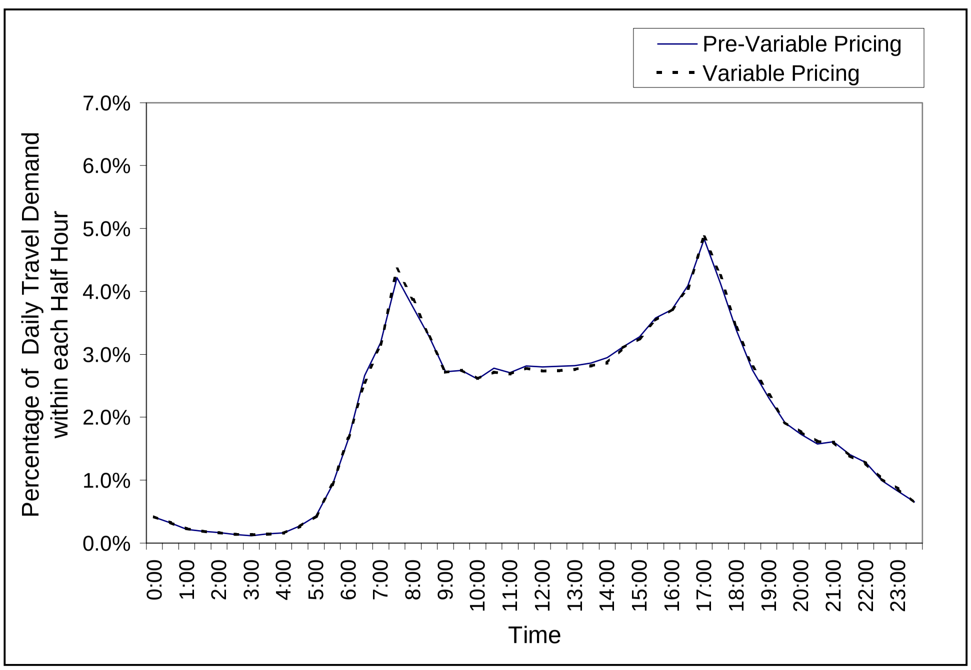

Figure 4: Temporal Distribution of Ineligible User Demand at the Cape Coral Bridge

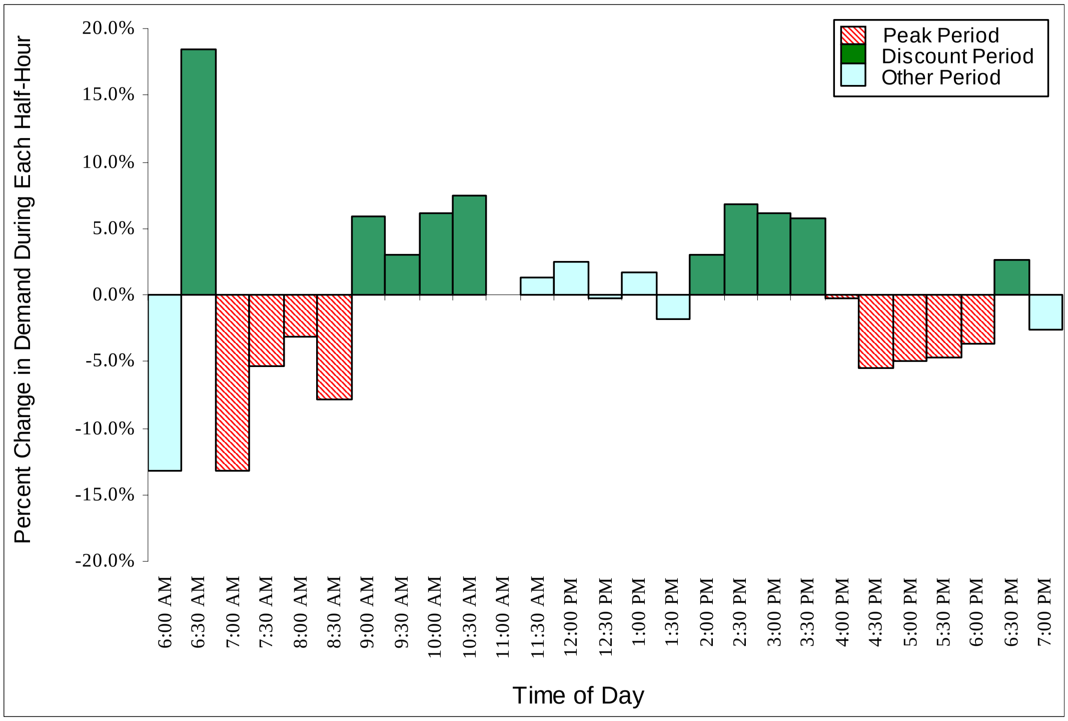

Figure 5: Eligible User Temporal Demand Shifts at the Midpoint Bridge

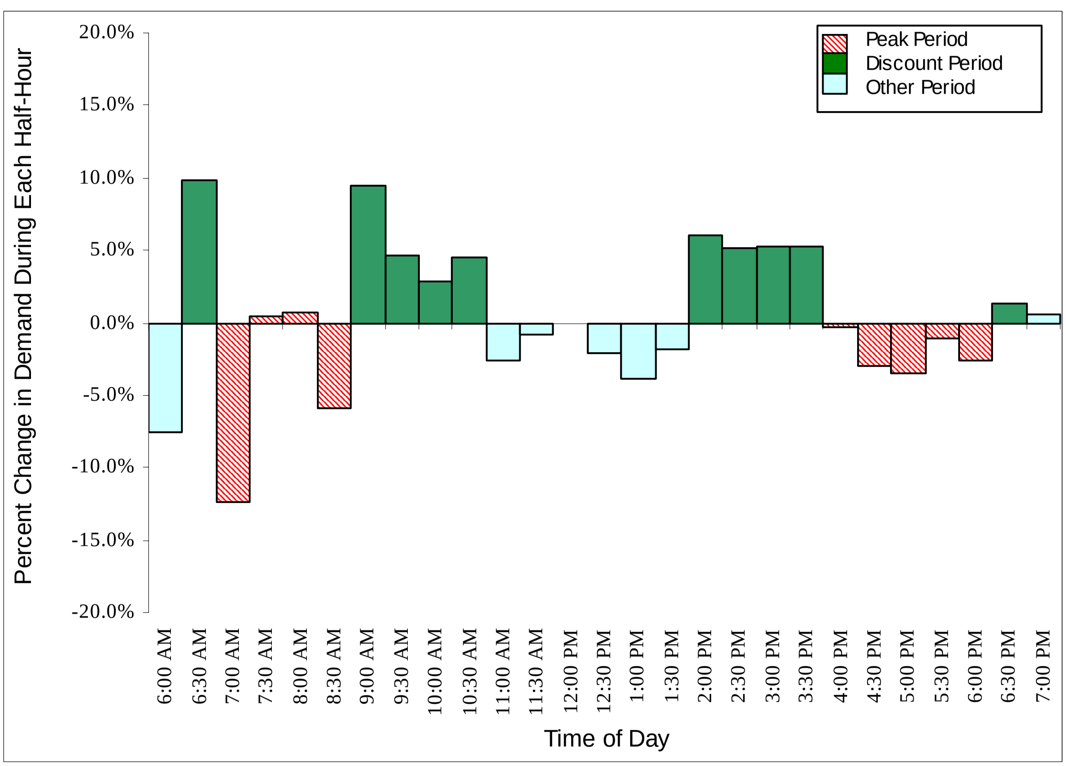

Figure 6: Eligible User Temporal Demand Shifts at the Cape Coral Bridge

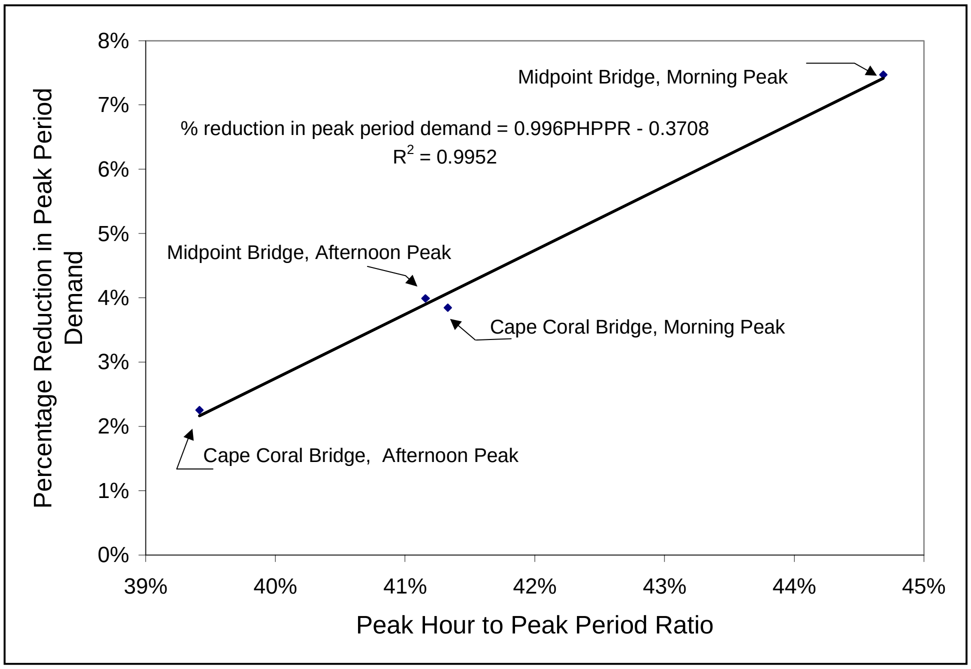

Figure 7: Peak Hour to Peak (Three Hour) Period Ratio against Percentage Reduction in Peak-Period Demand